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RESEARCH FINDINGS RELATIVE TO THE BIOLOGICAL EVALUATION OF SPRUCE BUDWORM INFESTATIONS IN OREGON

By

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RESEARCH FINDINGS RELATIVE TO THE BIOLOGICAL EVALUATION OF SPRUCE BUDWORM INFESTATIONS IN OREGON

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INTRODUCTION

Western forests are subject to recurrent outbreaks of defoliating insects of diverse species. Some of the outbreaks are short-lived; others continue for a period of years until subdued naturally or by direct control measures. The diversity in outbreak patterns emphasizes the need for appraisal surveys (now called evaluation surveys), as defined by Bongberg (1956), in order to determine biologically whether direct control is needed. However, the large number of outbreaks and the increased interest of land-managers in the impact of each outbreak has placed a heavy burden upon those assigned the appraisal job. It has become obvious that appraisal methods must be improved so that rapid, efficient appraisal surveys can be performed by a small but well-trained staff.

Appraisal or evaluation primarily involves consideration of three characteristics of an outbreak: (1) the extent of the forest area suffering damage, (2) the intensity of damage to trees, stands, and watersheds, and (3) the potential of the new insect brood to cause further damage, either in place or by spreading into uninfested areas. Other factors, such as the status of natural control factors, are given secondary consideration, but assume considerable importance when little change in extent and intensity of damage takes place. Aerial surveys reinforced by ground-checking, readily provide information on extent and boundaries of infestations, and particularly within one infested area, relative damage between stands. When aerial surveys are conducted annually over the same forested areas, some indication as to trend of the outbreak can be obtained from annual comparisons of acreage in arbitrary damage intensity classes. However, the damage pattern applies to the insect generation completing feeding and cannot be projected to determine trend. Aerial observation tends to emphasize cumulative damage, which is important per se, but may have little relation to existing populations. Quantitative data on the level of the new brood, and data showing the significance of damage can be obtained only through a ground survey. Such a survey requires a sound sampling basis and must make use of research findings to obtain maximum biological information for the time and manpower invested.

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Conventional ground-sampling methods to measure population levels are extremely time-consuming. For any one year, numbers of insects must be counted on samples taken from plots located systematically or at random within infested areas, with sufficient samples taken to obtain a desired accuracy. For trend purposes, measurements of populations must be obtained each year for the same developmental stage at the same plots and comparison made between levels recorded in successive years. Even though sequential sampling methods (Morris 1954, Waters 1955) have reduced the time required for sampling by the use of population classes rather than population means, the maintenance of a large number of trend plots is a formidable job. When the various infestations to be surveyed extend over wide areas, coverage by trend plots using conventional methods is not practicable without a considerable increase in the size of a survey staff.

Simplified survey methods are therefore needed for each major defoliator, to permit an accurate appraisal with the manpower on hand. Methods are needed which will:

1. Provide an accurate picture of population levels and trends for areas where the infestation is serious.
2. Be based on observations at a series of temporary plots.
3. Be utilized only during years when the hazard justifies such an appraisal.

OBJECTIVES OF RESEARCH PROGRAM

Aims of spruce budworm research in this region particularly pertinent to appraisal surveys have been: (1) The development of orderly sampling procedures based on sound biological information and knowledge of variation in populations between and within trees, (2) an understanding of the changes in population levels at different times during the life cycle, (3) the improvement of methods in predicting population trends, and (4) recognition of the basic relationships between population and damage. Studies on most of these phases are yet incomplete. However, sufficient information is available to expedite the conduct of appraisal surveys to a considerable degree.

Appraisal of spruce budworm infestations is logically directed to the egg stage, which occurs late in summer. Information is thereby obtained for the new brood, which will cause damage the following season. Furthermore, the information is available in time for a decision as to the need for control, which must be made during fall. However, the survey methods and interpretation of survey results must be based on research findings. The following should be provided by research: (1) Basic sampling procedures for obtaining data on population levels, (2) methods for measuring population trends, (3) standards for evaluating egg population levels in terms of number of larvae surviving to attack the buds during the following spring, and (4) standards showing the relation between larval populations attacking the buds and resulting tree damage.

Results presented in this paper are based on analysis of data collected during 1955-58 at five semi-permanent plots in eastern Oregon infestations. One plot was dropped during 1957 because populations became too low for fruitful study. The plots were selected to represent different conditions and were located in widely separated areas. Routine sampling was limited to Douglas-fir, the most common tree species expressing dominance, although several other susceptible tree species occurred in each plot. The plot consisted of five sub-plots located five chains apart on a compass line, with 5 to 7 dominant or co-dominant Douglas-fir trees marked for larval sampling at each subplot; two trees were marked at each sub-plot for egg sampling. Estimates of damage were mainly obtained annually; in some cases damage estimates were obtained by back-dating.

BASIC SAMPLING STUDIES

I. Procedures

General Considerations

- A. Basic Biological Information. The new brood, which will cause feeding damage the following year, appears late in July or early in August. At this time eggs are deposited in masses on the foliage of host tree species. For any one locality, egg deposition continues for about two weeks, and hatching requires about ten days. The tiny larvae issuing from the eggs conceal themselves amidst bark scales and lichens on the limbs and bole of the tree, where they overwinter. In spring the larvae leave hibernation and may or may not mine into old needles before attacking the opening buds. As the new shoots expand, larvae build silken shelters within which they feed on the new needles. The partially consumed needles gradually die and become reddish in color. Pupation takes place on the foliage in mid or late July.

The egg population is easily detected. Egg masses of the spruce budworm in Oregon are larger than those found in the Northeast, consisting usually of three or four rows and averaging between 40 and 45 eggs per mass. When hatching of eggs is complete, the shiny whitish new masses are easily visible for removal and counting. In addition, a large number of old egg masses persist on the foliage for a year or more. These, too, are readily seen and should be removed and counted.

- B. Restrictions on Sampling. The forest represents a vast sampling universe, consisting of a number of tree species which are attacked to a varying degree by the spruce budworm, and all age classes of trees of these species. It is therefore advantageous to employ restricted sampling: defining the tree species and size of trees to be sampled. This is logical, so long as the designated species and size classes represent an important part of the infested stands. In eastern Oregon (and in the Rocky Mountains) Douglas-fir and white fir are the two species most commonly attacked by the budworm and can be designated for sampling to the exclusion of other species. Sampling is logically restricted to dominants and codominants, 55 to 75 feet tall, and 10 to 20 inches in diameter, a common size class for these species in second-growth forests and a size which permits ready access to the crown for sampling purposes. It has been established that such trees harbor a majority of the budworm population within a stand. To obtain sufficient number of insects for analysis of data, it is necessary to restrict sampling to stands showing appreciable feeding.

Where comparisons are to be made between plots, it is necessary to sample one tree species at all plots. During the studies conducted during 1955-58, Douglas-fir was sampled at all plots, in preference to white fir. The reasons are: (1) its greater abundance on a variety of exposures and sites, (2) its higher economic value, and (3) its ability to withstand budworm feeding over a period of years without severe reduction in the number of growing tips. Studies have been initiated to compare populations and damage between Douglas-fir and white fir.

Considerations in Sampling Individual Trees

- A. Distribution of Population within Trees. The location of spruce budworm egg masses within the crown is of considerable importance. Distribution can be divided into two aspects: (1) horizontal - involving numbers of budworm on the outermost twigs, as compared with foliage more remote from the light, and (2) vertical - involving numbers of budworm on crown segments at different heights within the crown. Populations on vertical crown segments may be expressed in two ways: (1) absolute populations, which are the total insects on a whole branch or a proportion of the branches within a crown segment, and (2) population density, the number of insects found on a unit foliage surface. When whole branches are removed during sampling, the average number of insects on a unit area (square inches, square feet) of foliage expresses density. Foliage area is obtained by measuring the average foliated length of the branch and the maximum foliated width and calculating the branch area as two triangles of foliage. ^{2/} The 15-inch twig, which has a standard length and is considered to have a width varying within definite limits about a mean, may also be employed to show population density.

^{2/} In eastern Canada, calculations of foliage area are based on average branch width, rather than maximum width, and foliated length (Morris, 1955).

1. Horizontal distribution of egg masses was studied in two ways. One method was to divide sample branches into two parts: (1) 15-inch twigs and (2) remainder of the branch. The objective was to find whether number of eggs or egg masses on 15-inch twigs represented a consistent proportion of the branch population. Although foliage area was measured both before and after removal of twigs, it was not found practicable to compare areas involved, because the foliage on the remainder is extremely thin. The second method was a comparison of the number of new egg masses deposited on current foliage with those on older foliage. The impact of current and cumulative feeding upon these distributions was deduced by listing estimates of damage along with the proportions of budworm found on these units.
2. Vertical distribution of eggs and egg masses is of considerable importance in planning a sampling program. Early investigators believed that most of the budworm eggs were laid near the top of the trees. If this were so, it would be a problem to obtain access to the desired sampling stratum without felling the sample trees.

Data on the distribution of egg populations with the crown of Douglas-fir were obtained by dividing the tree crown visually into thirds, removing one branch from each crown third, and examining the branches for egg masses. Total population found on whole branches was used as an expression of absolute population. Total population divided by the foliage area of each branch was used for expressing population density. An attempt was made to recognize changes in population distribution as the population increased, by sampling ten trees each year for a three-year period at a study plot near Baker, Ore. For various reasons, the same ten trees were not sampled throughout the three year period. Analysis of distribution of populations was based on five trees used both in 1955 and 1956, and on five trees used both in 1956 and 1957. Subsequently it was found desirable to test the distribution for all ten trees used in 1956. Less intensive information was obtained by sampling five trees in one year at plots in three other localities. Analysis of variance was calculated to determine if significant differences in population occurred between crown positions. Both number of eggs and number of egg masses were used as dependent variables. Number of eggs is regarded as the most reliable dependent variable, since considerable variation may take place in number of eggs per mass.

- B. Sampling Position. Selection of sampling position on the tree requires consideration of foliage distribution as well as population distribution. If time were no object, the tree could be sampled by the systematic removal of a fractional part of the total branches. This is not economically feasible for survey purposes and rarely so for research purposes. Therefore, it is desirable to determine the crown position at which representative population estimates for the tree may be obtained, in terms of both absolute population and population density.

Data on distribution of foliage by crown thirds were obtained in 1955 in the vicinity of the Baker plot, where tree crowns were reasonably symmetrical. Fifteen dominant or codominant Douglas-fir trees were felled, the crown divided into thirds and total number of branches in each third recorded. Every fourth branch was removed and measured for foliage area and number of 15-inch twigs. The proportional number of branches sampled in relation to the total number of branches in each crown third was considered in calculating total foliated branch area and total number of 15-inch twigs in each crown third. Although regression analysis could have been used to determine the distribution of foliage, one hypothesis was tested first - that the distribution of foliage in the crown would follow that for the surface of a right cylindrical cone. If this hypothesis were proven true, and if absolute egg populations were equal for each crown third, samples at midcrown would yield mean estimates of population density for the tree.

- C. Efficiency in Sampling. Initial efforts in sampling were based on the experience of researchers studying the spruce budworm in the Northeast and eastern Canada. Because of the limitations of time and manpower, the problem of sampling was attacked gradually; data on the efficiency of sampling units were accumulated as the studies progressed. With particular reference to sampling for egg populations, the approach was arbitrary but in line with general statistical procedures. Findings during the first year of studies on distribution of egg masses within trees encouraged continuation of this approach.
1. Variation in estimates of egg populations was studied by the removal of whole branches at midcrown from ten trees at each plot each year. Although the "half-branch" was found to be an efficient unit for sampling balsam fir in New Brunswick infestations (Morris, 1955), it was not used here because of the asymmetry of Douglas-fir branches. Egg masses were removed, separated into new and old, and the new egg masses examined for total number of eggs and percent hatching. The number of new egg masses found at each plot was expressed on three bases: (1) Ten whole branches (2) 1000 square inches of foliage area and (3) 100 15-inch twigs.

The adequacy of these three expressions of population level was determined by calculating the sampling error for the mean (standard error $\times$ "t") for each plot each year. Percent sampling error of the means (standard error $\times$ "t" divided by the mean) was the basis for comparing the three expressions of population level. In addition, data from plots with similar means (no significant difference at $p = .05$) were combined to determine the approximate number of branch samples needed to obtain a mean of predetermined accuracy at different population levels.

2. Variation in estimates of larval populations was studied at one plot in 1956 to determine the relative efficiency of two units: (1) whole branches obtained from the middle of the lower crown half and (2) 15-inch twigs removed by pole-pruner from the lower crown half. It was believed that for many purposes i.e. simple correlation of egg and larval populations, the use of two different sampling units could be justified. A comparison was made of the man hours required to obtain sampling estimates with the same accuracy using these two units. Two whole branches were removed from each of ten trees and four 15-inch twigs from each of 25 trees. It was expected that the time for collecting and examining samples would be approximately the same for the two sample lots.

II. Results

Considerations in Sampling Individual Trees

A. Distribution of Population within Trees.

1. Horizontal distribution of egg masses. From locality to locality, the proportion of population on the 15-inch twigs is fairly consistent, representing about half of the branch population, although variation between trees is high. It is shown (table 1.) that on Douglas-fir this proportion is not disturbed by severe defoliation, thereby indicating that number of egg masses on the twig quotient of the branch may have some value as a measure of population density. However, it is doubtful that this expression of density could be related to subsequent larval populations, since it has been shown (Carolin, 1950) that the proportion of larvae found on the 15-inch twigs is much greater than the proportion of eggs found on the twigs.

In contrast, the proportion of egg masses deposited on current foliage is quite consistent under conditions of light damage, but is rapidly reduced by greater defoliation. The latter expression of horizontal distribution appears to have no practical application in sampling.

2. Vertical distribution of egg masses.

- a. Branch populations. The analysis showed a significant increase in population, expressed both as number of eggs and number of egg masses, between years 1955 and 1956, but no significant change between 1956 and 1957. Using number of eggs, a significant difference between crown positions was shown to occur in 1955-56 for the five paired trees and in 1956 for the total 10 trees. In both instances populations in the upper third were significantly lower at $p = .05$ than those in either the mid or upper thirds. For 1955-56, this difference was not reflected by number of egg masses, while for 1956 trees alone number of egg masses in the upper third was significantly lower than those in the mid third. For the higher populations in the 1956-57 comparison, no significant difference in number of eggs was found between crown thirds. However, using number of egg masses, a significant difference was found, with the middle third being higher than both the low and upper thirds. These data are presented in table 2.

The general finding from the 3-year study is that, with (low) populations in the order of 350 eggs or less per midcrown branch, the upper crown third is likely to contain a lower number of eggs than low or mid-thirds. With higher populations, the tendency is toward similar populations throughout the crown. For the 5-tree lots from three other localities, the average branch populations were lowest for the upper third, but the difference was not significant at $p = .05$. With small numbers of trees, number of egg masses does not always accurately reflect number of eggs. However, as the number of trees is increased, use of egg masses rather than eggs as a variable would be a logical step in saving time spent in counting eggs.

- b. Population density. The analysis for the three-year study showed a significant change in density during 1955-56, but no significant change during 1956-57. For 1955-56 no significant difference in density between crown positions was found for either number of eggs or number of egg masses. For 1956-57, a significant difference in density of both eggs and egg masses occurred between lower and upper thirds, with the upper being highest. This condition results from similar absolute populations being found on large branches in the lower third and on small branches in the upper third. For the 5-tree lots from three other localities, the upper and mid thirds generally showed similar average densities, with the low third showing lower average densities. However, there was no statistical significance to these differences. These data are shown in table 3.

The general finding is that, as absolute populations increase and tend toward a uniform vertical distribution, population densities tend to become significantly higher in the upper crown third. The increased concentration of insects on these small branches containing a limited food supply, in terms of buds, could result in more striking damage in the upper crown third, other things being equal.

- B. Sampling Position. Foliage distribution was considered in relation to population distribution. Foliage area, expressed in thousand square inches, was found to be distributed vertically within the crown in the ratio: Lower third - 5, middle third - 3, and upper third - 1. In other words, there was no significant difference from the distribution calculated for the surface of a cone. However, when number of 15-inch twigs was used as an index of foliage surface, the proportion of foliage between the lower and middle thirds differed significantly from the theoretical proportion at $p = .05$. It may be argued that number of 15-inch twigs is an indication of active growth (no 15-inch twigs were counted which did not bear living buds) and that a gradual cessation of growth on the lower branches, due to shading, is responsible for the deviation from the theoretical distribution. It could also be inferred that the use of foliated branch area as a sampling unit for comparing larval populations between crown thirds could be misleading. Table 4 summarizes these data.

The comparison of branch populations by crown thirds did not consider number of branches per crown third. In table 5, it is shown that number of branches is similar for lower and middle crown thirds, whether or not internodal branches are considered, but that a consistently greater number of branches occurs in the upper third. This finding does not alter the hypothesis of similar absolute populations in the lower and middle crown thirds, which represent 8/9 of the tree's foliage. However, total populations in the upper third would be generally higher than originally surmised from individual branch counts, but would continue to be inconsistent, according to population level.

On the basis of these data, there is no reason to reject either the low or mid thirds as choices for sampling positions for spruce budworm eggs. Since the branches from the middle third are smaller than those from the lower third and are more efficiently collected and handled, the middle third can be arbitrarily selected for routine sampling of egg populations.

C. Efficiency in Sampling.

1. Variation in estimates of egg populations, based on a one-branch sample at midcrown from each of ten trees, was found to be quite high. However, from year to year, any one of the units was indicative of larval populations occurring the following spring. For expressing relative population levels for a number of plots, the sampling error is reasonable; for measuring trends by a comparison of population estimates from year to year at individual plots, the error is excessive. Two expressions of population - total number of egg masses on a branch and egg masses per 1000 square inches of foliage - showed similar sampling errors in terms of percent of the mean. Except at low population levels, total egg masses per branch showed a somewhat lower error. In general, number of egg masses per 100 15-inch twigs showed much higher sampling error than the other two expressions; at high population levels the error tended to be comparable. The time required to collect and examine a plot sample, disregarding travel time, was approximately 48 man hours.

Combination of data from plots showing no significant difference between the means at $p = .05$ permitted calculation of the average number of branch samples required for a desired accuracy. In general, a minimum of 30 to 50 branches is required to obtain a mean characterized by 20 percent sampling error at $\alpha = .05$; 120 to 200 branches are required for a 10 percent sampling error. This amount of sampling would be exorbitant for survey purposes with the existing staff and financing. A summary of sampling error obtained is given below, using $p = .05$.

<u>:Number of egg masses per branch:</u>				<u>:Number of egg masses/1000 sq.in.</u>			
:				::			
Population:	Number :	:Sampling error ::		Number :	:Sampling error		
level	:of plots:	Mean :	in percent	:of plots:	Mean :	in percent	
Low	3	4.9	27.6	3	2.47	26.5	
Medium	5	9.2	15.7	5	6.34	19.3	
High	3	25.6	20.8	3	12.36	22.8	

2. Variation in estimates of larval populations was sufficiently high for whole branch samples so that use of 15-inch twig samples removed by pole-pruner was considerably more efficient. The means obtained by the use of the two units and their respective sampling errors ($p = .05$) were as follows: (1) 20 whole branches - 14.1 ± 28 percent (2) 100 15-inch twigs - 2.26 ± 18 percent. The collection and examination time was as follows: (1) 20 whole branches - 37 man hours (2) 100 15-inch twigs - 30 man hours. It was calculated that 52 whole branches should be examined to obtain a sampling error, in terms of percent of the mean, similar to that for 100 15-inch twigs. Therefore, 2.5 to 3 times as much work is required to obtain accuracy similar to that obtained for the twig sample.

For showing certain relationships between egg and larval populations, such as survival from egg hatching until attack of the buds, it is necessary to use the same sampling unit. However, merely to establish a correlation between egg and larval populations, use of the two different units appears justified. Since sampling throughout the larval period and during the pupal stage is also conducted efficiently by the use of 15-inch twigs removed by pole-pruner, transition to efficient sampling should take place as soon as possible.

III. Conclusions

A. Distribution of Population within Trees.

1. No change in horizontal distribution of egg masses was found to occur with increasing defoliation of Douglas-fir, when proportion of masses on 15-inch twigs was used as a criterion. However, the proportion of egg masses found on new growth decreases rapidly with increasing defoliation.
2. With low populations, the number of eggs per branch is significantly lower in the upper crown third, with no significant difference between the low and middle thirds. As populations increase, there is a tendency toward equal numbers of eggs on branches throughout the crown.
3. With low populations, the density of eggs per branch expressed on the basis of foliage area is similar throughout the crown. As populations increase, there is a tendency toward higher densities in the upper third of the crown.

B. Sampling Position.

1. Distribution of foliage on Douglas-fir trees of prescribed sampling size approximates that for the surface of a right cylindrical cone, when foliage area is used as a unit of measurement. However, this distribution did not pertain when number of 15-inch twigs was used as a criterion, because of deviation from the expected proportion in the lower crown third.
2. Total number of branches is similar for the low and middle crown thirds, but higher for the upper crown third.
3. Either the low or middle crown thirds can reasonably be specified for routine sampling of egg populations.

C. Efficiency in Sampling.

1. Variation in estimates of egg populations is sufficiently high to make conventional sampling prohibitive for survey purposes.
2. Sampling errors, expressed as percent of the mean, are similar for (a) total number of egg masses per branch and (b) number of egg masses per 1000 square inches of foliage area. Higher error is found when number of egg masses per 100 15-inch twigs is used as a sampling unit.
3. Within plots, there is no advantage to expressing number of egg masses per branch in relation to foliated branch area for routine sampling purposes. However, between plots the expression of egg mass density in relation to foliage area provides a practical means of comparing egg populations.
4. Sampling of larval populations is much more efficiently performed by the removal of 15-inch twigs using a pole-pruner, than by the removal of whole branches.
5. While whole branches (or half-branches) are favored for sampling egg populations, because of considerable variation in horizontal distribution of masses between trees, the use of the 15-inch twig to sample larval populations appears appropriate for some purposes. Specifically it is believed that the two types of sampling units can be employed in attempting correlations between egg and resulting larval populations.

MEASUREMENT OF POPULATION TREND

I. Procedures

Two questions in particular needed answers:

1. Is the egg population estimate indicative of the larval populations which will attack the buds the following spring?
2. Do the numbers of old egg masses, in comparison with new egg masses, have any value in predicting trend?

Relation between Egg and Larval Populations

- A. Survival from Eggs to Feeding Larvae. Studies of survival to the bud-attack period were conducted at a plot of low population during 1955-56 (Baker) and at a plot of high population during 1956-57 (Dixie). Whole branches were used to measure both egg and larval densities. Attempts were made to measure some of the major factors affecting survival; the general effect of other factors was deduced.

Non-hatch of eggs from parasites, predators, and sterility was measured each year at all plots, including the two mentioned above. General observations on the effects of dispersion were made on a continuing basis. Mortality of larvae during hibernation was determined by examination of limb sections removed from trees in the general vicinity of the Baker plot during 1955-56, and from sample trees in the Dixie plot during 1956-57. Mortality during needle mining was not evaluated to any degree, since the incidence of needle mining varies between seasons and localities. At higher elevations, needle-mining often does not take place.

B. Comparison of Egg Density and Larval Density.

Two different sampling units were used to relate egg and larval densities. Density of egg populations was based on foliage area of whole branches removed at midcrown, while larval density was based on 15-inch twigs removed from the lower half of the crown by pole-pruner. In addition, density of egg masses expressed on a basis of 100 15-inch twigs was tested for relation to larval density, even though its utility was dubious. Because samples drawn from individual trees were small, plot averages are used as the basis for comparison. At each plot, ten trees were sampled for egg populations, and 25 trees for populations of larvae in the buds.

Tabulated data were simplified as much as possible (table 7.) Since average number of eggs per mass was similar for all localities considered, density of egg masses rather than eggs was used as an index of population. (One locality was not considered in analysis, because of apparent mixing of one and two-year strains.) Variation in percent hatch of eggs was attributed to sampling error if within the normal range of 80-90 percent hatching. In these data number of eggs per mass and percent hatch tended to be compensating. In one case where percent hatch was below 80 percent, due to unusually high egg sterility, the egg population density was corrected downward on the basis of 85 percent hatching.

The degree of association between egg mass density and larval density was tested by the statistical method of correlation. If correlation proved to be significant, regression analysis was to be attempted.

Comparison of Old and New Egg Masses

A. Significance of Density of Old Egg Masses.

Earlier work in eastern Oregon had shown a large proportion of old egg masses to persist in good condition until spring (Carolin 1950). During collections of egg mass material and examinations of foliage for damage in the fall, it was noted that some slippage of egg masses from the new growth of Douglas-fir took place. The reason was that the waxy covering of the new needles prevented good adherence of the fluid secreted with the eggs. The possibility of the loss of egg masses of new needles compensating for the persistence of some egg masses more than one year appeared worthy of exploration. The first requisite was the proper separation of old and new egg masses, which can be achieved by two steps: (1) examination of the condition of old egg masses during June, before the new generation appears, (2) during the regular examination, using egg masses on new growth as a guide to the appearance of new masses.

For each plot, density of old egg masses was tabulated for comparison with average density of new egg masses found during the previous year. Analysis of variance was attempted to determine whether the two population estimates were significantly different, using both egg masses per 1000 square inches of foliage and egg masses per 100 15-inch twigs.

II. Results

Relation between Egg and Larval Populations

A. Survival from Eggs to Feeding Larvae.

Studies of survival showed that approximately 10 percent of the initial egg population survives to attack the buds. Non-hatch of eggs, due to parasites, predators and sterility, normally represents a 10 to 20 percent reduction of the initial population. A considerable loss, due to dispersion by wind currents, accompanied by increased exposure to predators such as spiders, takes place as larvae leave the eggs to find hibernating locations and again when larvae leave hibernation to begin feeding. In between these two events, 15 to 30 percent of the larvae in hibernation are destroyed by predators. Although only a small fraction of the initial population will ultimately cause damage, slight variations in survival can have a marked effect on the size of larval populations.

B. Comparison of Egg Density and Larval Density.

Significant correlation ($p = .05$) between egg and larval densities was found when egg masses per 1000 square inches of foliage was used as the independent variable, but not when egg masses per 100 15-inch twigs was used. The correlation coefficient was 0.64 for the former and 0.53 for the latter. A regression line in the form $y = a + bx$ (fig. 1) was fitted to show the approximate relationship between egg masses per 1000 square inches (x) and larvae per 100 twigs (y). Because variance was found to increase rapidly with higher values of estimated y , the regression line was obtained by weighting estimated x and y values by $1/x^2$. The regression equation derived is:
 $y = 100 x - 172.5$.

For the eight plots with 2.7 to 8.2 egg masses per 1000 square inches (x), pooling the variance results in a relatively low sampling error for number of larvae (y): ± 44 at $p = .05$. Therefore, larval populations may be predicted with reasonable accuracy for low and medium egg populations; with higher populations the variance in estimated larval density is so high as to preclude reasonably accurate prediction. Some of the excessive variance is due to the limited number of records for higher populations; however, much of it may be due to striking differences in larval survival, characteristic at high population levels, and to variation in the characteristics of the 15-inch twig unit between localities. These factors will be discussed in more detail in reference to damage.

Comparison of New and Old Egg Masses

- A. Significance of Density of Old Egg Masses. It was found that, at four of five plots, the average number of old egg masses per 1000 square inches in a given year was similar to the average number of new egg masses per 1000 square inches found the previous year (table 8.). Analysis of variance, using the same trees from year to year, and in two instances ^{3/}unpaired trees, showed no significant difference ($p = .05$) between the two population densities at all five plots. While average densities based on 100 15-inch twigs showed a similar relationship between new and the following year's old egg masses, variance was too great to have confidence in the use of this unit.

^{3/} Measurements were replicated on only four trees at Chesnimnus and four trees at Joseph during the period 1955-56.

The approximation of this year's density of old egg masses to the previous year's density of new masses is based on a majority of the new masses remaining on the foliage for a year, a small percent remaining for two years, and a rapidly diminishing percent hanging on for three or more years. Therefore the observed relationship between new and old egg masses can be upset by a drastic reduction in a population which has persisted at a high level for several years. When an outbreak suddenly ends, as at Chesnimnus during 1955, a small percent of egg masses hanging on two or more years results in a numerically large carry-over of old egg masses, in comparison with the low population of new masses. It is believed the rather large difference between the two mean densities at Chesnimnus is due to this fact. That no significant difference was found between new and the following year's old egg masses at this plot is mainly attributed to a high sampling error.

It is believed that, for practical sampling purposes, the density of old egg masses can be used as an approximation of last year's population. When the egg population is drastically reduced from the previous year, the decline will be exaggerated but nonetheless valid. Therefore, the ratio of new egg mass density to old egg mass density can be used as an index to population trend at each plot sampled. This means that in eastern Oregon, and probably in the Rocky Mountains, trend information can be obtained by one sampling at temporary plots established and used only during a year when the hazard is deemed high.

III. Conclusions

A. Survival from Eggs to Feeding Larvae.

1. Approximately 10 percent of the initial egg population survives to attack the buds. This figure is approximate, and small variations in survival not detectable by sampling could have a significant effect on the size of larval populations.

B. Comparison of Egg Density and Larval Density.

1. Number of egg masses per 1000 square inches of foliage are significantly correlated with number of larvae per 100 15-inch twigs attacking the buds.
2. A reasonable sampling error was found for low and medium egg populations (2.7 to 8.2 egg masses per 1000 square inches) but variance was very high for high populations. More data dealing with high populations are needed.

C. Significance of Density of Old Egg Masses.

1. No significant difference was found at individual plots between the density of new egg masses and the density of old egg masses during the following year.
2. For practical sampling purposes, it is believed that the ratio of new to old egg masses can be used as an index to population trend.

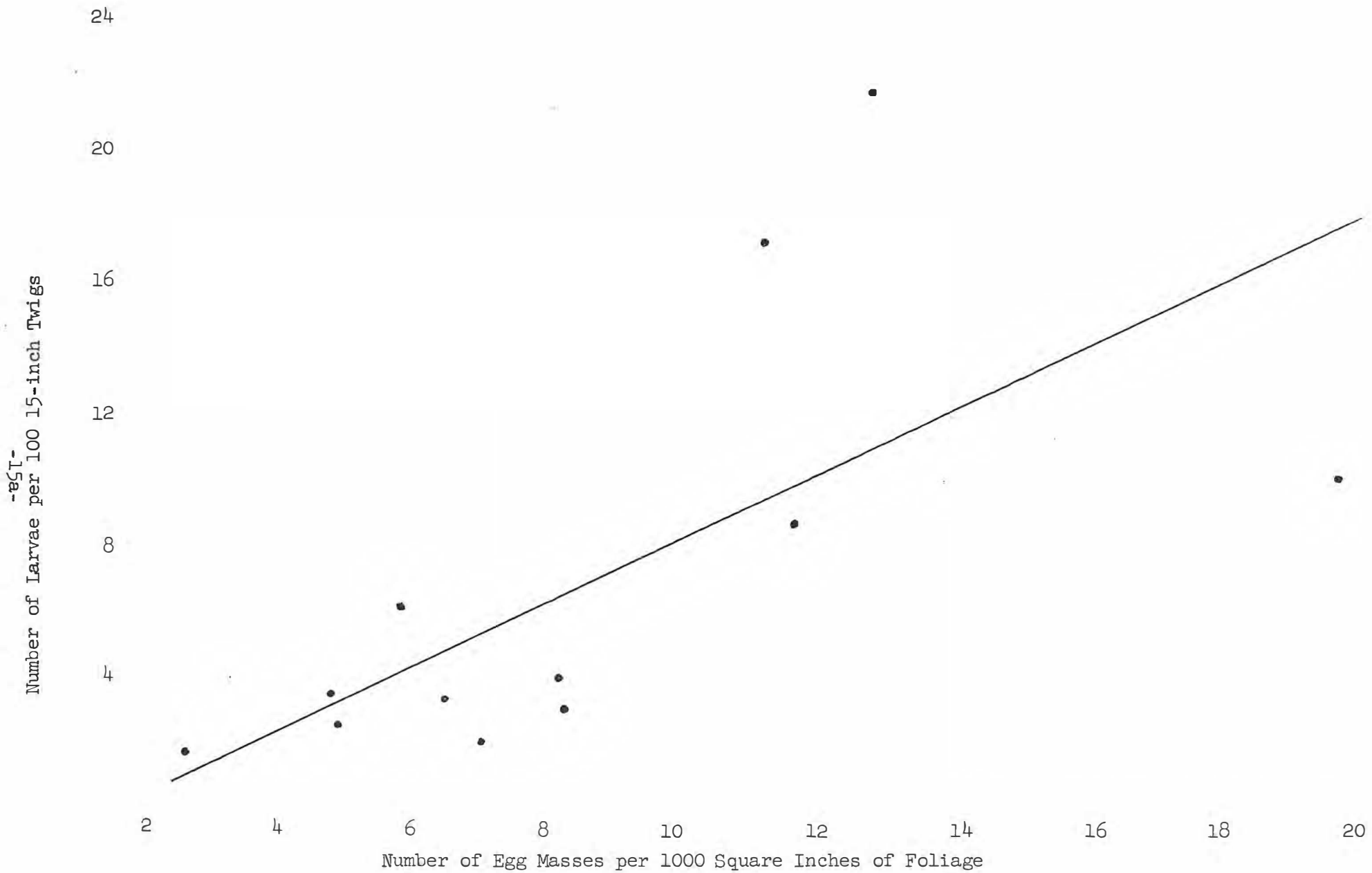


FIG. 1--RELATIONSHIP BETWEEN EGG POPULATIONS AND ENSUING LARVAL POPULATIONS ATTACKING BUDS

RELATIONSHIP OF LARVAL POPULATIONS TO DAMAGE

I. Procedures

Measurement of Annual Damage

Estimates of current damage were obtained annually at all plots. Plot estimates were based on estimates for individual trees, except when damage was uniformly very light. The purpose of obtaining estimates of annual damage was to determine whether these estimates could be correlated with larval populations attacking the opening buds. If density of larvae attacking buds could be predicted from estimates of egg density, and larval densities correlated with current damage, then the level of egg populations could be used to anticipate damage. It was desirable to treat the problem in two steps, since survival of feeding larvae might vary with locality, and characteristics of host trees in different localities could affect the damage incurred.

The external symptoms of annual damage are the degree of defoliation of the current needle growth, the incidence of bud-killing, and the amount of back-feeding on the older needle growth. Cumulative damage is shown by the degree of defoliation of all needle growth, reduction of the normal vegetative bud complement, top-killing, loss of annual increment, and tree mortality. Cumulative damage may have an effect on subsequent annual damage; reduction of the normal vegetative bud complement represents a reduction of the available food supply, and should tend to concentrate a budworm population on the remaining buds and shoots.

Percent defoliation of current growth was estimated in two ways: (1) by ground observation, using field glasses and (2) by removing sample twigs from specified crown positions and tallying percent defoliation and shoot or bud condition (living or dead) for each shoot on the sample. In the first method, the tree crown was divided visually into thirds and separate estimates based on the average of estimates by two observers, were obtained for each crown third. Average estimates for the tree were obtained by weighting midpoints of class estimates for crown thirds as follows: lower third - 5, middle third - 3, and upper third - 1. In the second method, samples were taken only from the middle crown third and estimates of damage on each shoot to the nearest 10 percent were made by one observer, while the second observer acted as tally man. The following categories were arbitrarily used to express estimates of percent defoliation for crown thirds. Midpoints of these classes were used to obtain refined estimates for trees and plots.

<u>Damage level</u>	<u>Defoliation percent</u>
Very light	0 - 10
Light	11 - 25
Moderate	26 - 50
Heavy	51 - 75
Severe	76 - 90
Extreme	91 - 100

Damage Relationships

- A. Correlation of Populations with Damage. At two of the plots, only light damage was recorded during the period of study. Since periodic examination of sample twigs during other studies showed no appreciable bud-killing at these plots, estimates of damage were concerned only with percent defoliation of current growth. These estimates were obtained with field glasses. At plots showing moderate and high populations, damage estimates were concerned both with current defoliation and bud-kill. Tallies of damage on individual shoots of sample twigs were the basis for these estimates. During 1957, estimates of defoliation were obtained both with field glasses and by shoot tallies at two plots with high populations.

The degree of association between number of larvae on 4 15-inch twigs and percent defoliation of growth on 15 to 25 plot trees was tested by statistical correlation. The relation between percent defoliation and percent bud-killing was also examined.

- B. Factors, other than Population, Affecting Damage. While defoliation may be related to population at one particular plot, similar estimated populations at different plots were noted to cause different degrees of damage on trees of specified sampling size. Some of this variation is due to inadequacies in sampling the population. However, three important factors affecting the amount of damage inflicted by similar populations have been noted: (1) foliage characteristics, particularly complement of buds on a unit foliage surface, (2) survival of larvae from the bud attack until the start of the pupal stage, and (3) timing of larval attack of the buds.
1. Complement of vegetative buds was determined for each plot except Chesnimnus^{4/} to attempt to explain differences in damage with similar larval populations per 100 15-inch twigs. During routine sampling for larval populations, at least two estimates of number of buds per 100 twigs were obtained while taking four 15-inch twigs from each of 25 plot trees. Incidence of bud-killing as disclosed by shoot tallies was considered as to its probable effect on normal bud complement.
 2. Larval survival from bud attack until the pupal stage is a critical factor in predicting damage, particularly defoliation, since the amount of feeding by an individual larva increases rapidly during the last instar. Larval numbers are reduced by parasites, predators, and droppage of larvae from the trees. The effects of these factors vary from year to year at any one plot. The proportion of larvae surviving during the feeding period must be relatively consistent to permit accurate prediction.

^{4/} This plot was dropped during 1957 for lack of measurable populations.

Total population reductions were measured at all plots by sampling 25 trees during the bud attack period and the same 25 trees when 25 to 50 percent pupation was reached. The latter sampling is timed to coincide with maximum attack by parasites affecting full-grown larvae, without permitting this group of parasites to abandon their hosts. Percent survival was determined at all plots for the period 1955-57 and tabulated to show variation. It was expected that survival would be different between plots of low and high populations.

3. Timing of larval attack of buds was explored by a deductive approach, considering two plots both with high larval populations but with different resultant damage to buds. If population density is not related to bud-killing, then the time at which larvae break hibernation or leave mined needles, in relation to expansion of the buds, is likely a major factor influencing bud-killing. (At elevations above 6000 feet, larvae hibernating on Douglas-fir usually move directly to the swelling buds, with little or no needle-mining occurring.) Rate of bud elongation, once swelling has commenced, may have an important bearing on susceptibility to bud-killing. Comparison of bud-killing and percent defoliation was made between the Dale plot, where bud damage was strikingly low, and the Dixie plot, where bud damage was high. Larval populations were expressed on the basis of 1000 buds, to remove the effect of different bud complements between the two plots.

- C. Changes in Defoliation with Increases in Population. The slope of the defoliation/population regression line is of particular importance. Establishment of a "damage curve" would enable prediction of percent defoliation, but not bud-kill, from population counts of larvae in the buds. The application of data from these studies is limited, because only the defoliation estimates based on field glasses could be correlated with populations on an individual tree basis. Comparison was made of damage curves within and between plots using individual tree records to provide data for analysis. Comparison of curves between plots was limited to those with similar bud complements. Analysis was made by the statistical method of covariance.
- D. General Relationship of Larval Populations to Damage. The relationship between populations of larvae attacking buds and defoliation of the current growth is shown in table 9. To compensate for variation in normal bud complement between plots, larval populations were expressed on the basis of 1000 buds. Average number of buds per 100 15-inch twigs was used for conversion. The basis for defoliation estimates was as follows: (1) uniformly low populations - a general estimate, based on examination of twigs during population sampling for full-grown larvae; (2) low to medium populations - individual tree estimates obtained by field glasses, averaged to obtain a mean for the plot; (3) high populations - individual tree estimates for the middle crown third obtained by shoot tallies on sample twigs, averaged to obtain a mean for the plot. Percent of larvae surviving until pupation is shown for each plot for each year.

The relationship between larval populations and defoliation was tested by the statistical method of correlation. In addition percent defoliation was plotted over number of larvae and a hand-drawn curve used to smooth out the data. Values were read off the graph to show the approximate relationship between population and defoliation categories already established. These figures form a basis for tentative standards which indicate the damage expected, in terms of defoliation, from different densities of larval populations attacking the opening buds.

II. Results

Damage Relationships

- A. Correlation of Populations with Damage. Since damage estimates were obtained by two different methods, correlation analyses were kept separate by method. The "x" variable was larval density, expressed as number of larvae on four twigs. In one plot, number of buds were counted on each sample twig, permitting a test of number of larvae per 100 buds as an "x" variable. Used as "y" variables were percent defoliation alone, percent defoliation with killed buds included as shoots with 100 percent defoliation, and, ~~if recorded,~~ percent buds killed.
1. Estimates with field glasses. Plots with low and medium populations will be considered first. At Baker correlation between population and defoliation was non-significant for 15 trees sampled in 1956 ($r = 0.45$) but highly significant for 25 trees sampled in 1957 ($r = 0.66$). At Joseph correlation was highly significant ($r = 0.77$) for 25 trees used in 1958. Significance in the correlation coefficients indicates that the observers were consistent in recognition of degree of defoliation; it is possible that the estimates could be consistently low or consistently high. Actually, the field glass estimates by a particular team of observers during 1957 were consistently low as compared with those based on shoot tallies. The fact that a relation between larval populations and damage could be found at a low population level is worth noting.

At plots with high populations, results were somewhat inconsistent. Correlation of larvae per 4 15-inch twigs and percent defoliation in 1957 was highly significant for 14 trees at Dale, but non-significant for 25 trees at Dixie, where damage was very heavy. However, when populations for trees in the Dixie plot were expressed on the basis of 100 buds, a significant correlation was found ($r = 0.45$). At both plots, correlation was also attempted using a corrected percent defoliation which included killed buds as shoots with 100 percent defoliation. Percent bud-kill was obtained from estimates based on shoot tallies. This procedure merely lowered the correlation coefficients.

2. Estimates from shoot tallies. For the high populations at Dale and Dixie in 1957, these estimates were not as satisfactory as those based on field glasses. Correlations between number of larvae per 4 15-inch twigs and percent defoliation were not significant. When populations on trees at Dixie were expressed on the basis of 100 buds, correlation was non-significant. For 14 trees at Dale, both in 1955 and 1956, no significant correlation was found between number of larvae and defoliation. Inclusion of buds killed as shoots showing 100 percent defoliation did not lead to improved correlation in any of these analyses. An attempt to correlate percent defoliation and percent bud-kill showed that there was no significant association of these two characteristics of damage.
3. Comparison of the two methods. Defoliation estimates with field glasses, where separate estimates for each crown third are combined to obtain an average for the tree, are much more likely to be related to populations than are estimates based on shoot tallies for the middle crown third. If samples for shoot tallies had been taken from each crown third, average defoliation would no doubt have been better shown. While estimates based on field glasses in 1957 were lower than those from shoot tallies, it is apparent that observers can be consistent from tree to tree in applying the defoliation classes previously listed.

Field glass estimates can be obtained rather rapidly, if light conditions are satisfactory, whereas examination of twigs to tally defoliation on individual shoots is very time-consuming. Accurate estimates of the incidence of bud-killing can only be obtained from shoot tallies. Although bud-killing appears to be unrelated to actual population level, it is presumed to be an important factor in damage suffered by a tree.

B. Factors, other than Population, Affecting Damage.

1. Complement of vegetative buds was found to vary considerably between localities under study, and to a lesser extent between individual trees at one locality. Stand density is the most obvious factor affecting bud complement of trees, although growth habit appears to differ between trees at different elevations. Variation in average bud complement for four plots is shown below; these data are presented by subplots, consisting of five trees, to show variation within plots.

Number of Vegetative Buds on 20 15-inch Twigs

Stand Density	Plot	----- Subplots -----					100 Twigs Total
		<u>1</u>	<u>2</u>	<u>3</u>	<u>4</u>	<u>5</u>	
Closed	Baker	534	430	343	447	337	2091
"	Dixie	429	570	566	407	440	2412
Open	Joseph	720	559	777	735	527	3318
"	Dale	551	678	999	1045	796	4069

The normal bud complement, and what it represents in terms of food for the budworm, may be altered by severe bud-killing. At Dixie during 1956 and again in 1957, 43 to 52 percent of the vegetative buds were killed. Most of the killed buds were replaced by smaller adventitious buds. In 1956, the ratio of buds replaced to buds killed was 0.91 and in 1957 0.89. The permanent loss of buds each year was only about 5 percent of the total number of buds. However, the ease with which the budworm destroyed undersized adventitious buds the second year of attack showed that the food capacity of the trees was greatly lowered.

The complement of staminate flower buds was not a significant factor affecting defoliation on Douglas-fir at low populations. No instances of heavy flower production occurred in plots with higher populations. Flower production on Douglas-fir is generally light and years of heavy production infrequent, compared with the true firs.

2. Larval survival from the bud attack until 25-50 percent pupation was found to average 39 percent, with a range of 30 to 54 percent. In other words, only one out of every 2.5 larvae successfully attacking the buds will survive until the start of pupation. Unusually high survival was found at two plots, Baker and Joseph, during 1956. Both plots were characterized by low populations and light damage; increased damage due to higher survival was not noticeable. At the Baker plot, the higher survival was attributed to the striking absence of larval droppage to the understory during the feeding period. Variation in survival during the feeding period is shown below.

<u>Percent Survival</u>	<u>Number of Plots</u>	<u>Percent Survival</u>	<u>Number of Plots</u>
30-33	2	46-49	0
34-37	5	50-53	1
38-41	3	54-57	1
42-45	0		
		Total	12

The time at which unusually high insect mortality takes place is extremely significant in the amount of damage incurred by a tree. With the spruce budworm, populations often suffer heavy reductions by parasites at the end of the feeding period. These reductions are rarely reflected in decreased damage. Variation in survival from the end of the larval period until the end of the pupal period is greater, as shown below.

<u>Percent Survival</u>	<u>Number of Plots</u>	<u>Percent Survival</u>	<u>Number of Plots</u>
22-29	2	54-61	1
30-37	2	62-69	1
38-45	2	70-79	1
46-53	3		
Total			12

3. Timing of larval attack of the buds was deduced to be of considerable importance. At the Dale plot, where no needle-mining was found in 1957 or any other year, larvae breaking hibernation went directly to the opening buds. At the Dixie plot, where needle-mining occurred in 1957, larvae attacked swollen buds, which remained well swollen without breaking, for about ten days. Larval survival up to pupation was similar at both plots, and percent defoliation was not strikingly different. The difference in bud-killing was, however, very noticeable. The following comparison shows that factors other than population density, presumably governing timing of attack, are responsible for the incidence of bud-killing.

<u>Plot</u>	<u>Year</u>	<u>Rate of Bud Expansion</u>	<u>Larvae per 1000 Buds</u> (Number)	<u>Percent Defoliation</u>	<u>Percent Bud-kill</u>
Dale	1956	Rapid	418	75-80	16 ^{5/}
	1957	do.	533	do.	6
Dixie	1956	?	-	85-90	46
	1957	Slow	427	do.	52

- C. Changes in Defoliation with Increases in Population. Within plots, only one comparison could be made. At Baker, no significant difference was found between regressions obtained in 1956 and 1957. At other plots, field glass estimates for defoliation were obtained for only one year, and annual estimates of defoliation based on shoot tallies could not be correlated with population on individual trees.

^{5/} Most of the bud-kill was due to frost. Estimates made during examination of twigs for larval populations attacking the buds were that 5 to 15 percent of the buds were killed on individual twigs.

Between plots, comparisons were made on the basis of similar bud complements. Number of buds per 100 15-inch twigs were almost identical for Baker and Dixie, and were reasonably similar between Joseph and Dale. In both cases, the plots compared represent one with low populations and one with high populations. The Baker-Dixie comparison showed entirely different regressions (fig. 2). It is probable that the regression at Dixie is abnormal, due to reduced foliage production from the substitution of adventitious buds for vegetative buds. The Joseph-Dale comparison showed the regressions to be barely different at $p = .05$ (fig. 3); it is probable that if population levels had not been so drastically different the regressions would not be significantly different.

- D. General Relationship of Larval Populations to Damage. Statistical analysis showed a highly significant correlation between larvae per 1000 buds (populations entering the opening buds) and resulting percent defoliation of the new growth. With the limited data on hand, the relationship is assumed to be linear, although with a greater number of plots a curvilinear relationship might become evident. The relationship is shown graphically in figure 4.

To establish tentative standards, classes of larval populations were selected and the range in percent defoliation corresponding to these classes read from the graph. These figures are tabulated below to show the general relationship between larval numbers and defoliation, and qualitative terms are applied to express the general level of population and damage.

<u>Number of Larvae per 1000 buds</u>	<u>Population Class</u>	<u>Percent Defoliation</u>	<u>Defoliation Class</u>
Less than 50	Very low	Up to 15	Very light
51-150	Low	15-25	Light
151-300	Medium	25-50	Moderate
301-500	High	51-90	Heavy

III. Conclusions

A. Correlation of Populations with Damage.

1. Visual estimates of percent defoliation on individual trees based on field glass estimates for each crown third are usually related to the density of larval populations on these trees. It is believed that the method of weighting estimates for each crown third by the proportional amount of foliage in each crown third aids considerably in establishing this relationship. Observers show consistency in their estimates from tree to tree, but may be consistently high or low in their estimates.

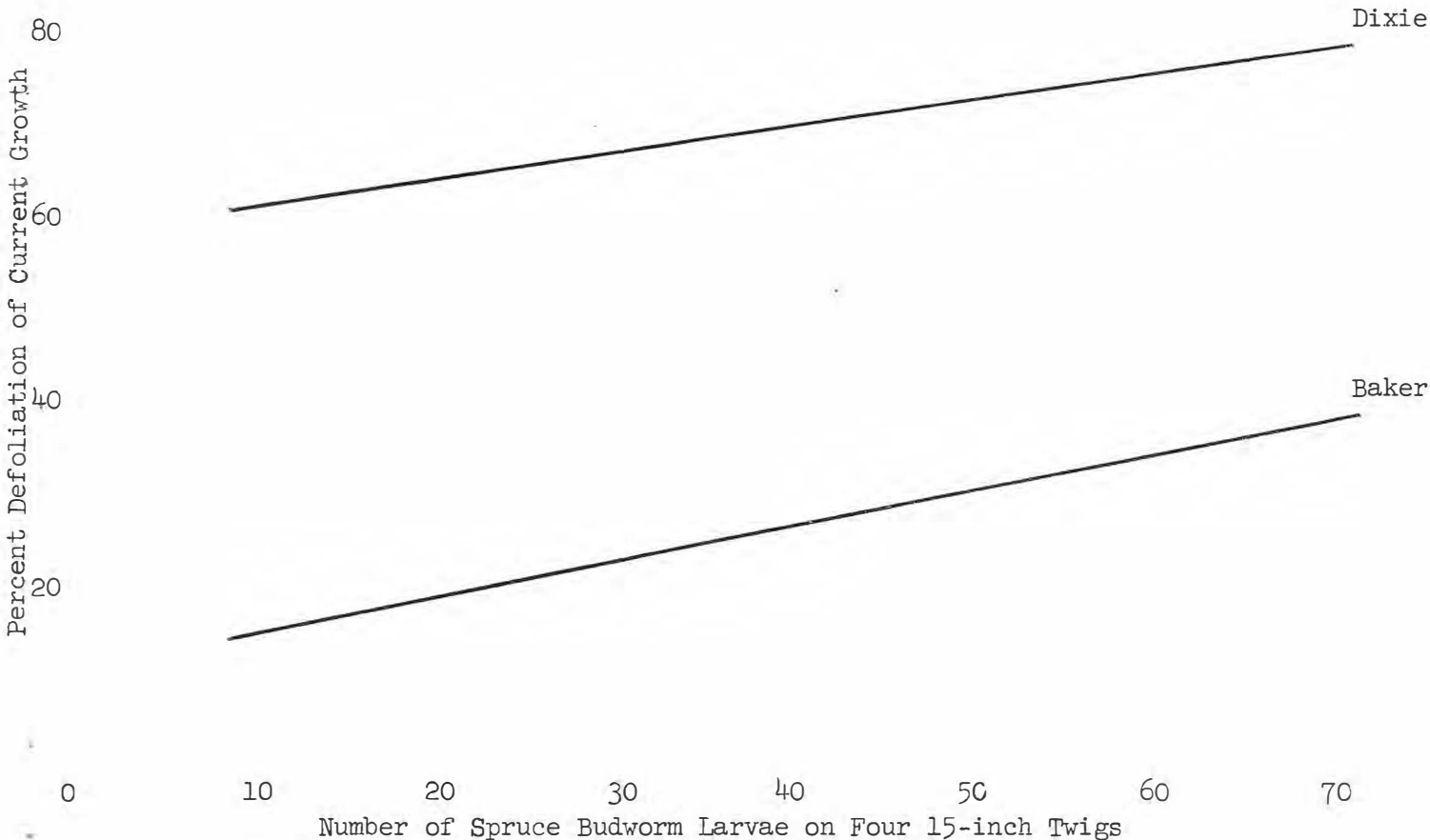


FIG. 2--RELATION BETWEEN LARVAL POPULATIONS AND PERCENT DEFOLIATION OF CURRENT GROWTH FOR TWO LOCALITIES WITH LOW BUD COMPLEMENTS.

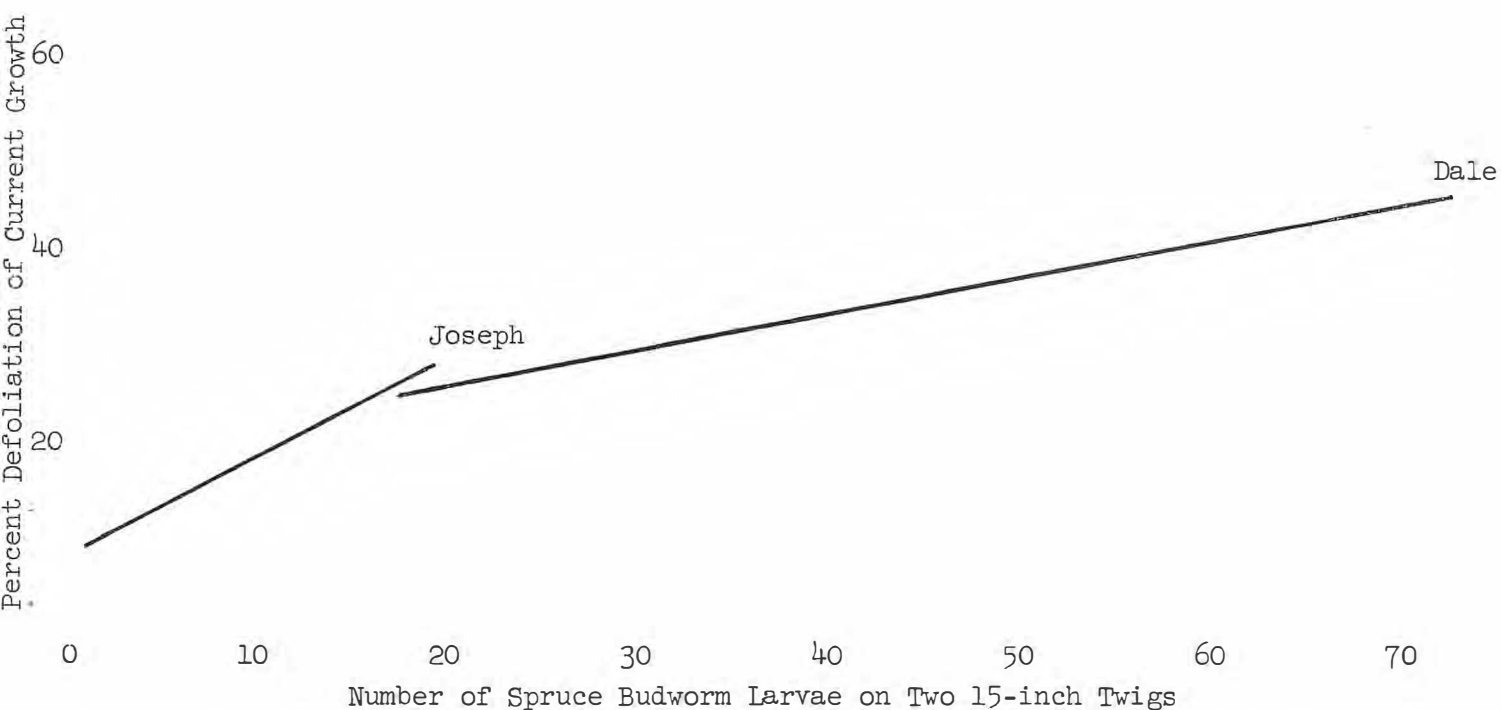


FIG. 3--RELATION BETWEEN LARVAL POPULATIONS AND PERCENT DEFOLIATION OF CURRENT GROWTH FOR TWO LOCALITIES WITH HIGH BUD COMPLEMENTS.

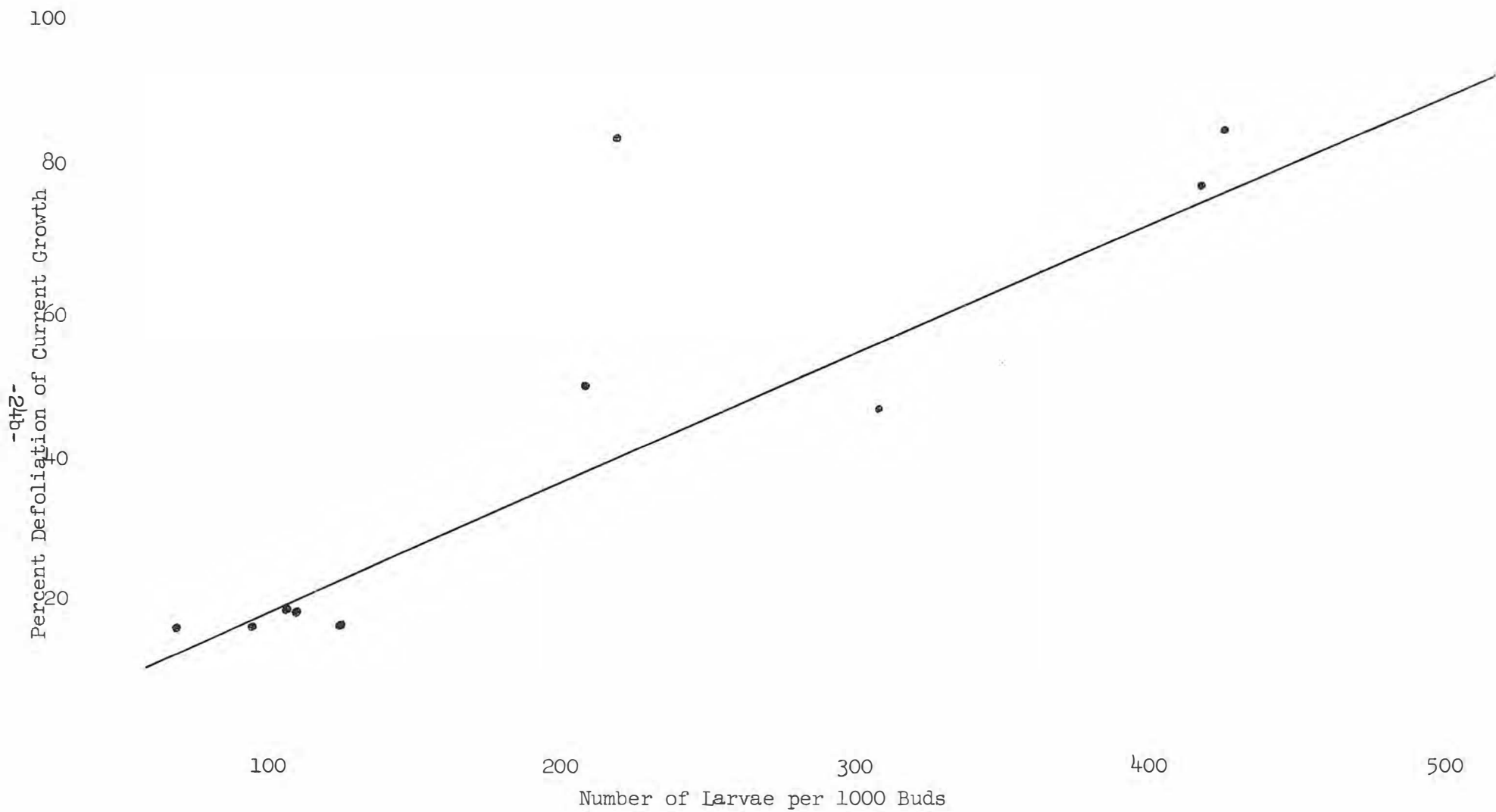


FIG. 4--RELATION BETWEEN LARVAL POPULATIONS, EXPRESSED ON A BUD BASIS, AND PERCENT DEFOLIATION OF CURRENT GROWTH. (PLOT AVERAGES USED.)

2. Estimates of percent defoliation based on shoot-tallies for the middle crown third are not closely related to density of larval populations on these trees. However, these estimates probably yield a more accurate picture of defoliation and bud-killing for the plot, than do field-glass estimates. On individual trees the foliage sample is apparently too small to encompass the normal variation within a crown third.
3. The incidence of bud-killing is not directly related to population level, or to percent defoliation. Intensity of bud-killing is believed to be an important damage factor, but its effect on tree increment was not evaluated in these studies.

B. Factors, other than Population, Affecting Damage.

1. To establish area-wide damage relationships, larval populations should be expressed on the basis of number of larvae per 1000 buds. This is shown by the variation between localities in number of buds per 100 15-inch twigs on sample trees, and by the successful correlation of larvae per 1000 buds with defoliation at the heavily damaged Dixie plot, where larvae per 100 15-inch twigs was not correlated with defoliation.
2. Larval survival between plots from the bud attack period until 50 percent pupation is not sufficiently different to preclude correlation between larval density and damage. However, survival from 50 percent pupation until the end of the pupal period varies considerably, but occurs too late to have a significant effect on percent defoliation.
3. Timing of larval attack of the swelling buds is deduced to be a major factor affecting bud-killing. The factors responsible for delayed bud-opening were not explored in these studies.

C. Changes in Defoliation with Increases in Population.

1. Attempts to establish damage/population curves between areas were not successful, although within one plot the damage/population curves were not significantly different over a two year period. Analysis by the method of covariance appears suitable for comparing damage/population curves, if population density is expressed by number of larvae per 1000 buds, rather than number per 100 twigs.
2. Previous damage, resulting in heavy bud-killing, distorts the normal damage/population relationship.

D. General Relationship of Larval Populations to Damage.

1. Using plot averages, the relationship of larval populations per 1000 buds to percent defoliation of current growth is highly significant. By the use of population classes, the population level can be used to predict damage in terms of percent defoliation of current growth.

2. A table is presented to show this relationship for infestations in eastern Oregon.

APPLICATION OF FINDINGS

I. Objectives

The purpose of this paper is to apply research findings to the conduct of evaluation surveys. Since the areas of infestation are easily defined by aerial survey, the objectives of the ground survey are to: (1) determine population trend (2) measure population density and (3) forecast damage. The intensity of survey needed for confidence in the results over a large area cannot be readily determined from research studies. Conduct of a survey on as intensive a basis as possible should provide the answer to this question.

II. Sampling Methods for Surveys

- A. Sampling Design. The general area in which the spruce budworm is found in the Pacific Northwest is normally characterized by several well-defined infestations. Geographical boundaries, non-susceptible types, and other factors conspire to make infestation boundaries relatively clear-cut. Because infestations arise at different times and persist for varying periods of time, each infestation may be considered a separate universe. Sampling should be limited to those infestations in which budworm feeding represents an immediate hazard. This limitation is consistent with the purposes of evaluation.

Stratified random sampling, as employed in the research studies, is a practical approach to sampling infestations. The stratum is defined as young second-growth stands, characterized by dominant and co-dominant firs 55 to 75 feet tall and 1.0 to 20 inches d.b.h.. Such stands are of high economic value and are a common component of both east-side and west-side forests.

- B. Selection Methods. Selection of stands for sampling should be done from a map of the infestation. Because of increased variation in estimates with lower populations, selection should be limited to stands showing at least 25 percent defoliation. This level is well within the recognition of aerial observers, and coincides with the upper part of the range of feeding by low populations. If a large proportion of an infestation is characterized by moderate or heavy damage by aerial observation, the stratum to be sampled can be defined as young second growth stands (as above) showing moderate to heavy damage. As shown by research studies the difference between moderate and heavy damage does not necessarily represent a difference in population density.

Since variation in population levels between stands within an infestation is totally unknown and since the amount of sampling that can be done in each infestation is limited by manpower, recommendations as to number of plots are purely arbitrary. It is proposed that the minimum number of stands sampled in any infestation be four, with one plot per stand, and that the minimum distance between plots be two miles for small infestations and four miles for large infestations. Thus the maximum number of plots for a small infestation of 10,000 acres would be five. For larger infestations, it is proposed that a 4-mile grid be used as a basis for marking possible plot locations. After a decision is made as to number of plots that can be sampled with existing limitations in manpower, one of the random selection methods can be used to select a proportion of the plots for sampling.

- C. Sample Estimates. The ten-branch sample at midcrown has been shown adequate for determining population trends, through comparison of old and new egg masses, and for indicating the general level of population. Since variation within trees even in the same crown third is known to be high, it is recommended that the plot sample consist of two branches taken at midcrown from each of five trees. To reduce the work of examination, it is proposed that the branches be reduced to half-branches as defined by Morris (1955), by trimming all the twigs off the left-hand side of one branch and off the right-hand side of the second branch.

Branch samples should be examined by a crew of qualified examiners, preferably women. Experience in eastern Oregon has shown that women are more patient and thorough in performing such work. Two conditions expedite accuracy in examining the foliage for egg masses: (1) good working conditions - including natural light found outside under light shade, and comfortable seats and tables, (2) a requirement that all needles bearing insect material, whether it be single eggs of the black-headed budworm or scale insects, be removed and saved. A qualified male employee should supervise the work, checking examined foliage at intervals. He should: (1) separate insect material found on each branch into spruce budworm and other (2) make entries on the note form as to branch dimensions and total number of spruce budworm egg masses found on each branch, and (3) package all material in gelatin capsules by branch, tree, and plot.

Separation of egg masses into new and old should be performed by a person with previous experience on this work, or under the supervision of an experienced worker. Previous checking for old egg masses during June and comparison of egg masses found on new growth with those on old growth form a basis for accurate separation. In each infestation a proportion of the egg masses should be checked for average number of eggs per mass and approximate percent hatching.

III. Analysis of Data

- A. Population Trend. The ratio of old to new egg masses on each branch furnishes an index of trend. If sufficient numbers of egg masses are found, an index number can be calculated for each branch and an average determined for the plot. Results for all plots should be compiled by infestation, to determine whether the trend is consistent between plots in an infestation and between infestations. Since average density of new egg masses is needed for other analyses, the ratios can be based on densities of old and new egg masses if desired.
- B. Population Density. Number of new egg masses on each branch should be divided by the foliated area to obtain number of egg masses per 1000 square inches, and a mean branch density determined for each plot. The density determined for each plot should be accompanied by an estimate of number of eggs per mass and percent of eggs hatching. These are the salient data for predicting the level of resulting larval populations attacking the opening buds.

As a result of research, a table has been prepared to show the relation between egg and larval populations and the amount of defoliation to be expected. This table is based on the following conditions prevailing in eastern Oregon during 1955-58: (1) approximately 42 eggs per mass and (2) 80 to 90 percent of the eggs hatching. The survival of larvae hatching from eggs until attack of the buds in spring is incorporated into the table. Any deviations from the two conditions above would require conversion of figures in the table. While populations are classified only in five broad classes, a specific range of larval populations and resulting defoliation is indicated.

- C. Damage. Research studies have shown that a serious factor in damage -- bud-killing, is not directly related to population level. It was also shown that following a high incidence of bud-killing a given degree of damage occurred at a lower population level, apparently due to reduction in size of buds and shoots. Therefore it is necessary to obtain annual estimates of damage at each plot to forecast accurately the severity of bud-killing and defoliation the following year.

It is proposed that estimates of percent defoliation based on field glasses be obtained by crown thirds for each plot tree, using the categories tested in research studies, except that the categories 51 to 75 percent and 76 to 90 percent should be combined. These categories in percent are: 0-10, 11-25, 26-50, 51-90, and 91-100. Where variation in plot trees warrants it, average defoliation for each tree can be obtained by weighting estimates for low, mid, and upper crown thirds by 5, 3, and 1 respectively. Under conditions of light defoliation, it would be logical to make estimates only for the middle crown third, although the middle third has not yet been proven to show average defoliation for the tree.

Measurement of percent buds killed is also necessary. For this purpose, twig samples should be removed at random from the lower half of the crown by pole-pruner. The twigs are examined to determine total number of buds and number of buds killed. More than 40 percent of the buds killed is considered severe damage. The removal of twigs for this purpose is also an opportunity for observers to check on their estimates of percent defoliation.

- D. Summary. Use of the methods proposed here will permit conduct of a survey to forecast budworm activity for the coming year with reasonable accuracy. Further improvement in methods is needed to permit an increased number of plots to be sampled in each infestation. A better understanding of the significance of damage factors is needed. Through research and coordination of research and evaluation efforts, improved surveys will eventually be developed.

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Table 1.-Horizontal distribution of spruce budworm egg masses on midcrown branches of ten Douglas-fir trees in each of five localities in eastern Oregon, 1955-57

Locality	Year	Percent	Number	Percent Egg Masses Deposited on			
		current defoliation	new egg masses	Current growth	Old growth	15-inch twigs	Branch remainder
Baker	1955	10-25	32	22	78	44	56
	1956	15-25	80	34	66	34	66
	1957	"	112	33	67	51	49
Chesnimnus	1955	10-25	78	45	55	58	42
	1956	"	57	33	67	54	46
Joseph	1955	"	71	34	66	59	41
	1956	"	54	30	70	46	54
	1957	"	36	42	58	39	61
Dale	1955	50-60	195			52	48
	1956	75-90	339	19	81	49	51
	1957	75-90	121	18	82	47	53
Dixie	1956	90-100	509	2	98	43	57
	1957	"	233	4	96	53	47

Table 2.-Differences in absolute spruce budworm egg populations within the crown of Douglas-fir, as shown by analysis of variance of estimates for three crown positions.

Locality	Years	Number of trees	Average population			--- Total number of eggs ---			a/ Significant difference in population	Nature of difference
			Low	Mid	Upper	Year	Crown position			
BAKER	1955-56	10	242	150	52.5	S	S	1956 > 1955,	L > U, M > U	
	1956	10 ^{b/}	338	265	90	-	S		L > U, M > U	
	1956-57	10	196	494	281	NS	NS			-
CHESNIMNUS	1955	5	306	223	164	-	NS			-
JOSEPH	1955	5	245	234	98	-	NS			-
DIXIE	1957	5	1283	1002	625	-	NS			-
--- Total number of egg masses ---										
BAKER	1955-56	10	4.8	3.7	1.5	S	NS	1956 > 1955,		-
	1956	10 ^{b/}	6.2	8.5	3.2	-	S		M > U	
	1956-57	10	4.3	10.6	5.8	NS	S		M > L, M > U	
CHESNIMNUS	1955	5	9.4	6.4	4.0	-	NS			-
JOSEPH	1955	5	6.0	7.4	3.4	-	NS			-
DIXIE	1957	5	28.0	25.2	14.0	-	NS			-

a/ p = .05

b/ A separate analysis was made for 1956 data since a significant difference in populations was found for 1955-56.

Table 3.-Differences in density of spruce budworm egg populations within the crown of Douglas-fir, as shown by analysis of variance of estimates for three crown positions

Locality	Years	Number of trees	NUMBER OF EGGS PER 1000 SQUARE INCHES FOLIAGE SURFACE						Significant difference in population ^{a/}
			Crown position			Crown position			
			Low	Mid	Upper	Year	position	Nature of difference	
BAKER	1955-56	10	159.9	127.3	127.1	NS	NS	1956 > 1955	-
	1956-57	10	118.8	257.8	466.4	NS	S		U > L
CHESNIMNUS	1955	5	220.2	287.2	416.8	-	NS		-
JOSEPH	1955	5	162.4	247.2	128.2	-	NS		-
DIXIE	1957	5	412.0	446.0	528.0	-	NS		-
NUMBER OF EGG MASSES PER 1000 SQUARE INCHES FOLIAGE SURFACE									
BAKER	1955-56	10	3.2	3.1	3.5	NS	NS		-
	1956-57	10	2.6	5.8	10.4	NS	S		U > L
CHESNIMNUS	1955	5	26.8	48.7	46.0	-	S		-
JOSEPH	1955	5	9.1	21.2	18.3	-	NS		-
DIXIE	1957	5	9.1	11.2	12.1	-	NS		-

^{a/} p = .05

Table 4.-Vertical distribution of foliage on Douglas-fir trees near Baker, Oregon, 1955

Tree number	D.b.h. (Inches)	Height (Feet)	Foliated Branch Area (M. sq.in.)				Number of 15-inch Twigs			
			--- Crown third ---				--- Crown third ---			
			Lower	Middle	Upper	Total	Lower	Middle	Upper	Total
1	12.7	63.0	66.4	56.5	14.3	137.2	400	352	72	824
2	16.4	78.0	105.0	72.2	22.4	199.6	676	596	172	1444
3	12.7	76.5	62.1	54.2	15.8	132.1	400	324	84	808
4	13.0	66.5	70.0	48.4	19.7	138.1	296	396	140	832
5	14.5	73.4	79.7	48.4	14.5	142.6	552	356	80	988
6	12.8	54.2	77.2	66.1	20.5	163.8	556	468	124	1148
7	11.6	63.6	43.7	35.6	12.5	91.8	268	280	92	640
8	13.2	69.2	87.3	53.8	11.3	152.4	412	368	84	864
9	11.7	56.2	112.2	91.8	22.4	226.4	680	688	120	1488
10	11.6	67.8	44.2	27.8	10.3	82.3	316	224	80	620
11	12.7	62.0	65.0	42.5	11.0	118.5	416	248	68	732
12	10.7	68.3	36.9	23.8	9.1	69.8	356	220	68	644
13	9.9	53.3	56.4	27.9	7.7	92.0	328	140	48	516
14	8.8	53.0	41.2	22.6	10.8	74.6	304	140	80	524
15	9.8	55.1	47.1	31.4	14.0	92.5	284	204	76	564

Table 5.-Vertical distribution of branches on Douglas-fir trees
near Baker, Oregon, 1955

Tree number	Number of Primary Branches				Total Number of Branches ^{a/}			
	---- Crown third ---- :				---- Crown third ---- :			
	Lower	Middle	Upper	Total	Lower	Middle	Upper	Total
1	39	40	54	133	39	40	82	161
2	51	48	58	157	51	56	82	189
3	36	42	67	145	36	42	79	157
4	36	38	40	114	36	42	80	158
5	47	52	44	143	47	68	128	243
6	45	47	52	144	45	55	88	188
7	40	40	54	134	44	48	78	170
8	52	47	44	143	52	47	96	195
9	55	50	32	137	63	66	76	205
10	49	47	53	149	49	63	101	213
11	34	39	50	123	34	43	90	167
12	58	61	60	179	62	77	112	251
13	35	27	48	110	47	39	72	158
14	50	39	38	127	54	51	110	215
15	40	42	46	128	40	54	86	180

^{a/} Number of internodal branches has been added to number of primary branches.

Table 6.-Estimates of spruce budworm egg populations on midcrown
branches of Douglas-fir trees at five localities in
eastern Oregon, 1955-57

Locality	Year	Number of Sampling Units			Number of New Egg Masses		
		Branches	1000 sq.in.	15-in. twigs	Branches	1000 sq.in.	100 15-in. twigs
Baker	1955	10	6.73	66	32	4.8	21.2
	1956	do.	14.04	79	80	5.7	35.4
	1957	do.	17.95	127	112	6.2	44.7
Chesnimnus	1955	do.	12.03	135	78	6.5	33.3
	1956	do.	20.85	148	57	2.7	20.9
Joseph	1955	do.	12.62	141	71	5.6	29.8
	1956	do.	25.71	200	54	2.1	12.5
	1957	do.	23.47	167	36	1.6	8.4
Dale	1955	do.	17.59	172	195	11.1	58.7
	1956	do.	26.66	252	339	12.7	65.5
	1957	do.	25.65	216	121	4.7	26.4
Dixie-Malheur	1956	do.	25.88	186	509	19.7	118.3
	1957	do.	21.97	141	233	10.6	87.2

Table 7. Relationship between average density of spruce budworm egg masses and density of larvae on Douglas-fir trees at five localities in eastern Oregon, 1955-58

Locality	Year	Total number of egg masses		Number of eggs/mass	Percent hatching		Number of larvae			
	ovi-position	1000 sq.in.	100 15-in.twigs				Year	100 15-in.twigs	1000 buds	Percent defoliation
Chesnimnus	1956	3.2	27.7	41	89	::	1957	141	--	10-25
Baker	1955	5.0	22.7	43	86	::	1956	227	124	10-25
Dale	1957	5.0	28.5	45	79	::	1958	324	63	(sprayed)
Baker	1956	5.7	30.4	42	81	::	1957	596	264	15-25
"	1957	7.2	51.2	48	91	::	1958	310	137	(sprayed)
Chesnimnus	1955	7.3	36.6	41	84	::	1956	190	--	10-25
Baker	1954	7.5 <u>b/</u>	26.6 <u>b/</u>	--	--	::	1955	281	124	10-25
Dixie	1957	8.4 <u>a/</u>	70.5 <u>a/</u>	42	64	::	1958	385	136	(sprayed)
Dale	1954	12.4 <u>b/</u>	60.5 <u>b/</u>	--	--	::	1955	851	174	50-60
"	1955	12.7	66.6	39	89	::	1956	1714	350	75-80
"	1956	13.3	71.2	42	90	::	1957	2186	446	75-80
Dixie	1956	20.1	108.6	41	85	::	1957	1010	429	85-90

a/ Figures are corrected to coincide with median of 85 percent hatching.

b/ Figures are based on old egg masses found during 1955.

Table 8.-Comparison of densities of new and old spruce budworm
egg masses on midcrown branches of Douglas-fir trees
at five localities in eastern Oregon, 1955-57

Locality	: Years	: Number of egg masses per 1000 square inches					
	: Previous:	Old	: New	: Old	: New	: Old	
	: epidemic:	in	: in	: in	: in	: in	
	: status :	1955	: 1955	: 1956	: 1956	: 1957	
Chesnimnus	7	32.8	7.3 <u>a/</u>	13.3 <u>a/</u>	--	--	
Baker	1	7.5	5.0	5.6	5.7	5.8	
Joseph	1	11.2	6.5 <u>a/</u>	5.6 <u>a/</u>	2.3	3.5	
Dale	1	12.4	12.7	12.4	13.3	15.2	
Dixie	1	--	--	9.7	20.1	19.3	

a/ Only 4 trees replicated for the period 1955-56.

Table 9.-Relationship between number of larvae per 1000 buds and percent defoliation of current growth on Douglas-fir trees at four localities in eastern Oregon, 1955-57

Locality	: Year	: Larvae per 1000 buds	: Survival to pupation	: Defoliation of current growth
		<u>Number</u>	<u>Percent</u>	<u>Percent</u>
Joseph	1956	68	53	10-25
"	1955	94	41	"
Baker	1955	107	36	20
"	1956	108	54	20
Joseph	1957	131	31	10-25
Dale	1955	208	39	54
Baker	1957	284	41	47 ^{a/}
Dale	1956	418	35	78
Dixie	1957	427	35	86
Dale	1957	533	33	79

^{a/} Original estimate based on field glasses was raised one category, since comparison of the two types of estimates during 1957 showed observers using field glasses to be consistently one category low.

Table 10.-Relationships between egg mass density, larval density,
and percent defoliation of current growth for spruce
budworm populations in eastern Oregon

Number of egg masses per 1000 sq.in.	Number of larvae per 1000 buds	Population level	Percent defoliation
0 - 3	Less than 50	Very low	Up to 15
3 - 5	51 - 150	Low	15 - 25
5 - 9	151 - 300	Medium	25 - 50
9 - 15	301 - 500	High	51 - 90
Over 15		Very high	90 - 100